Hawaii's Climate Change and Marine Disease Local Action Strategy

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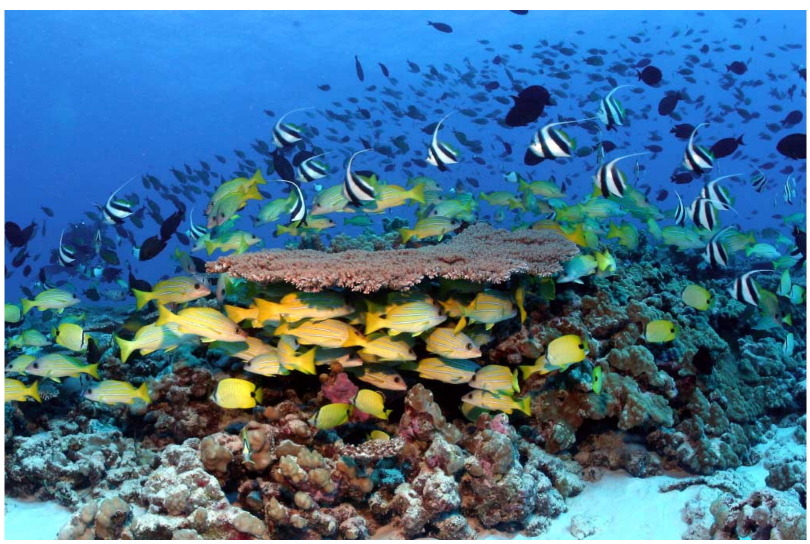

Developed by:
Department of Land and Natural Resources - Division of Aquatic Resources,
in concert with the Climate Change and Marine Disease Steering Committee

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List of Acronyms

CDHC	Coral Disease and Health Consortium
CRAMP	Coral Reef Assessment and Monitoring Program
CRED	Coral Reef Ecosystem Division
CREIOS	Coral Reef Ecosystem Integrated Observing System
DLNR DAR	Department of Land and Natural Resources, Division of Aquatic Resources
EEZ	Exclusive Economic Zone
EPA	Environmental Protection Agency
HFS	Honolulu Field Station
LAS	Local Action Strategies
MAAs	mycosporine-like amino acids
MHI-RAMP	Main Hawaiian Islands Rapid Assessment and Monitoring Program
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
PIFSC	Pacific Island Fisheries Science Center
PAR	Photosynthetically Active Radiation
SST	Sea Surface Temperature
UH	University of Hawaii
USCRTF	United States Coral Reef Task Force
USFWS	United States Fish and Wildlife Service
USGS	United States Geologic Survey
UV-B	Ultra Violet radiation- B
WHAP	West Hawaii Aquarium Project

Chapter 1: Introduction

Background of US Coral Reef Task Force and Local Action Strategy

Coral reef ecosystems are naturally dynamic and geologically resilient, but their ecosystem functions are being threatened worldwide by accelerated and novel environmental changes due to human activities. In 2002, the US Coral Reef Task Force (USCRTF) identified six management focus areas based on a prioritization of nationwide threats: coral reef fisheries, land-based pollution, lack of public awareness, recreational use, coral bleaching, and reef organism disease. The USCRTF requested that each United States jurisdiction develop three-year plans, or local action strategies (LAS), for each of the priority threats and tasked the federal members of USCRTF to work with the local jurisdictions on their development.

This LAS marks the completion of Hawaii's LAS process. Final LAS exist for Coral Reef Fisheries Management, Land-Based Pollution Impacts to Reefs, Recreational Impacts to Reefs, and the Living Reef Program (Lack of Public Awareness LAS). In addition, Hawaii recognized alien species as a priority management area and created the Aquatic Invasive Species Management Plan. Copies of these LAS are available by request to DLNR DAR.

The last two threats identified by the USCRTF, coral bleaching/climate change and disease, are both being addressed in this LAS. The threats are being combined into one LAS because there is some overlap in personnel, projects, and funding sources, but the combination does not imply a particular relationship between the two threats.

LAS Development Process

All LAS are multi-organization collaborative efforts that incorporate stakeholder input and guidance. The development of the Climate Change and Bleaching LAS was written by Dr. Greta Aeby, Melissa Bos, and Katie Siegler of DLNR. A steering committee was assembled to direct the creation of the strategy.

<u>Steering Committee Members:</u>
Athline Clark, DLNR DAR
Steve Coles, PhD., Bishop Museum
Paul Jokiel, PhD., University of Hawaii, HIMB
Jean Kenyon, PhD., NOAA PIFSC / CRED
Randy Kosaki, PhD., NOAA, NMSP
Jim Maragos, PhD., USFWS
Bob Richmond, PhD., University of Hawaii, PBRC
Rod Salm, PhD., and Eric Co, The Nature Conservancy
Wendy Wiltse, PhD., EPA Hawaii
Cindy Hunter, PhD, University of Hawaii
Ruth Gates, PhD., University of Hawaii, HIMB
Thierry Work, DVM., USGS

Non-local advisors:
Andy Bruckner, PhD., NOAA
Jennifer Kozlowski, NOAA, NOS
Cheryl Woodley, PhD., CDHC

The steering committee was formed in 2005 and assisted in collecting information and developing an initial background paper on coral bleaching and disease. After developing the LAS goals and objectives, the committee selected and prioritized projects. Numerous researchers, NGOs, and management agency staff provided their expertise and helped to write the description of each project. The draft LAS was circulated for review and comments to researchers, NGOs, and management agency staff. The LAS was circulated and available for public comment in July, with a final draft released in April 2007. Unlike the other Local Action Strategies in Hawaii listed above which focus on the Main Hawaiian Islands, this LAS covers a larger geographic scope covering the entire Hawaiian Archipelago.

LAS Goals and Objectives

Goal
To understand and manage impacts to reef ecosystems from climate change and marine disease for increased resistance and resilience.

Objectives
1. To support research that provides a scientific basis for managing impacts to reef ecosystems from climate change and disease.
2. To increase public awareness and engage stakeholders in monitoring and reporting bleaching and disease.
3. To develop rapid-response contingency plan for events of bleaching and disease.
4. To develop proactive and mitigative long-term management strategies to increase resistance and resilience of reef ecosystems to impacts from climate change and marine disease.
5. To develop a program to monitor the impacts of climate change and marine disease on the reefs of the Hawaiian archipelago.

LAS Implementation

The agencies involved in the creation of the Climate Change and Marine Disease LAS will also be responsible for its implementation. The steering committee will facilitate implementation through group meetings. DLNR staff will facilitate the steering committee activities and ensure that the LAS goals and objectives are met. As implementation of the LAS progresses, the committee may decide to hire a coordinator to provide oversight and guidance.

Chapter 2: Background/literature review

Coral bleaching/Climate Change

Reef corals contain symbiotic, single celled algae (zooxanthellae) that provide over 90% of a coral's energy budget. Coral bleaching, which is the loss of symbiotic zooxanthellae or the photosynthetic pigments from individual zooxanthellae, results in an energy drain on the coral that can lead to reductions in growth, reproduction or even death. Coral bleaching can occur in response to stress such as changes in salinity, light irradiance or temperature. However, mass bleaching events are usually associated with increased sea surface temperatures. In 1997-98, mass bleaching occurred on reefs throughout the world that resulted from increased sea surface temperatures associated with El Nino (Wilkinson et al. 1998, Wilkinson 2000). Severe bleaching can result in loss of live coral and a general decline in the integrity of coral reef ecosystems. An estimated 16% of the world's coral reefs were damaged during the 1997-1998 bleaching event (Wilkinson et al. 1998). It is predicted that the impacts of global climate change will result in more frequent and extensive bleaching episodes. It is critical that resource managers have sufficient information available which will allow them to make decisions on how to maintain the reef resources in the face of changing climatic conditions.

Research on coral bleaching in Hawaii

Studies on coral bleaching in Hawaii have been ongoing since the 1970s. The following review highlights some of the major research findings to date: Coles et al. (1976) tested the thermal tolerance of corals from both subtropical Hawaii and the tropical Marshall Islands and found that corals from the Marshall Islands had a higher temperature threshold than did the Hawaii corals. They concluded that differences in coral thermal tolerances correspond to predictable differences in the ambient temperature patterns between geographic areas, and that corals throughout the world are living within 1-2 degrees C of their upper limit during the summer months. Further experiments relating effects of temperature on energetic processes using measurements of oxygen flux suggested metabolic adaptation of corals to their ambient temperature regime. Corals show optimum growth near the local summer temperature maxima. Above normal summer ambient temperature results in both a decrease in photosynthesis to respiration ratio in corals as well as a reduction in carbon fixation (Coles 1973, Coles and Jokiel 1977).

Studies with altered temperature and light regimes showed that high light levels interact with increased temperature to produce coral bleaching and that duration of exposure to both temperature and irradiance will contribute to the degree of bleaching observed in corals (Coles 1973, Jokiel and Coles 1977, Coles and Jokiel 1978).

Jokiel (1980) found high levels of solar irradiance and exposure to UV both interact with high temperature to produce coral bleaching. Damage from UV radiation is well documented in numerous organisms and it has been found that corals have mycosporine-like amino acids (MAAs) which are thought to mitigate the damage from UV radiation by absorbing UVR and releasing it as heat (Dunlap et al. 1986)). Kuffner et al. (1995) examined the MAA concentration in four species of Hawaiian corals at different depths within two habitats having very different water spectral qualities. She concluded that the concentration of MAAs in the tissues of corals were inversely related to the amount of UV radiation received by the corals. Jokiel et al. (1997) found that MAA production is also increased when corals are exposed to high levels of photosynthetically active radiation (PAR) and high water velocity. Hence, observed differences in MAAs under different environmental conditions may be due to a combination of factors. This also suggests that corals living in higher water energy environments may be less prone to bleaching. Kuffner (2002) looked at the relationship between UV exposure, water motion and production of MAAs in the common reef coral *Porites compressa*. She found that both exposure to UVR and increased water motion enhanced production of MAAs in corals.

Bleaching events in Hawaii

Jokiel and Brown (2004) report on the first large-scale coral bleaching to occur in the Hawaii region. This occurred predominantly in Kaneohe Bay in 1996. The bleaching event was attributed to increases in SST and high light during a cloudless period. Differences in bleaching susceptibility among genera were noted with pocilloporids and montiporids showing the highest level of bleaching and having the highest mortality following the event. Overall bleaching mortality was estimated at ~2%.

A mass-bleaching event due to increased SST was documented in the Northwestern Hawaiian Islands (NWHI) in 2002 (Aeby et al. 2002, Kenyon et al. 2006). The backreefs of the three northernmost atolls (Pearl and Hermes, Midway and Kure) were most affected by bleaching. Pocilloporids and montiporids were found to be most susceptible to bleaching. Another minor event was observed in 2004 with patterns of bleaching being consistent with what was observed in 2002 (Kenyon and Brainard in press).

Jokiel and Brown (2004) show that the SST in Hawaii has increased over the past couple of decades. Increases in other oceans have also occurred due to global warming. They predict that if the warming trend continues then bleaching events will continue to occur in the Hawaii with increasing frequency and severity.

Marine disease

Disease can be defined as any impairment of vital body functions, systems, or organs. The causal agent of a disease can be either biotic or abiotic. Biotic diseases are those in which the causal agent is a living organism such as bacteria, viruses or macroparasites. Abiotic diseases result from environmental stresses such as changes in physical conditions or exposure to toxic chemicals. There has been a worldwide increase in the reports of diseases affecting marine organisms (Harvell et al. 1999). In the Caribbean, mass mortalities among organisms in reef ecosystems have resulted in major shifts in community structure. For example, the mass mortality of sea urchins in the early 1980s throughout the Caribbean resulted in massive algal overgrowth and contributed to phase shifts from coral- to algae-dominated reefs (Hughes 1994, Lessios 1998). Disease has also been implicated in the dramatic decline of acroporids, one of the major frame-building corals in the Florida Keys, changing the structure and function of the coral reef ecosystem (Aronson and Precht 2001, Patterson et al. 2002). It is unknown whether the emergence of these disease outbreaks are due to the introduction of novel pathogens as suggested for the outbreak of sea fan disease (Smith et al. 1996, Jolles et al. 2002) or to changes in pathogenicity of existing pathogens due to deteriorating environmental conditions and/or reduced host resistance (Harvell et al. 1999, Green and Bruckner 2000). It is predicted that changing environmental conditions associated with global climate change will result in future increases in diseases of marine organisms (Harvell et al. 2002), lending new urgency to understanding the epizootiology of marine diseases.

Studies conducted on coral disease in Hawaii

Past studies

Reed (1971) reported abnormal, discolored nodules on *Porites* colonies in Kaneohe Bay and Cheng and Wong (1974) determined the cause of the nodules to be a larval digenetic trematode. Aeby (1998a) documented the cause of this disease to be the metacercarial stage of the digenetic trematode, *Podocotyloides stenometra*. This disease, termed *Porites* trematodiasis, was found to suppress the growth of *Porites compressa* by up to 50% (Aeby 1991, 1992). This disease has been reported from reefs on both the main and Northwestern Hawaiian Islands. A survey of six reefs in Kaneohe Bay, Oahu for a two and a half year period showed the disease to be wide-spread throughout the Bay, to occur in all depth zones, to persist through time (years) and show no seasonality (Aeby 1998b).

Hunter (1994, 1998) quantified the distribution and temporal progression of tissue necroses and "tumors" on *Porites lobata* and *P. evermanni* colonies at three sites in the main Hawaiian Islands. Changes in overall coral cover over a seven year time period at each site were quantified using benthic video transects. Visual surveys were conducted at a number of sites to measure the occurrence of necroses and "tumor" distributions relative to colony size, depth, and distance from shore along randomly deployed 50 m transects. Macrophotographs were used to follow changes of affected areas on *Porites* colonies. Histological analysis of a variety of affected coral tissues was conducted (Hunter and Peters 1993, Hunter 1994, 1998, Hunter et al. 1999). Necroses were most likely to spread from the initial affected area. "Tumors" were observed to increase in size, become necrotic, or, in one case, be replaced by apparently normal tissue. The incidence and extent of necroses was positively correlated with colony size, while the incidence of "tumors" was independent of colony size. Neither showed a correlation with depth or distance from shore. Necroses and "tumors" appeared to be chronic and relatively frequent on *Porites lobata* and *P. evermanni* at all sites surveyed in the main Hawaiian Islands, although they were particularly apparent at Hanauma Bay, Oahu, both in number and proportion of coral tissue affected.

The USGS Honolulu Field Station (HFS) was established in 1992 to provide technical assistance to conservation agencies in Hawaii and the Pacific for wildlife health-related issues. The HFS also does applied research on diseases of free-ranging wildlife with an eye to formulating appropriate management recommendations. Currently, the HFS is working on diseases of reef fish, corals, marine invertebrates, and sea turtles. Surveys of coral health and categorizing of lesions has been done in Hawaii (Work and Rameyer 2001, Work et al. 2002), American Samoa (Work and Rameyer 2002, Work and Rameyer, 2005), and Johnston Atoll (Work et al. 2001). Thus far, it has been found that corals appear to be affected by tumors and lesions caused by parasites, bacteria, and fungi.

Current studies

Broadscale coral disease surveys were initiated in the NWHI in 2002 supported by DAR and the NWHI Coral Reef Ecosystem Reserve. In 2003, 73 sites were selected for long-term monitoring at nine islands/atolls across the NWHI and were surveyed to quantify and characterize coral disease. Annual monitoring for coral disease has subsequently occurred in 2004 and 2005. Baseline coral disease surveys were initiated in the main Hawaiian Islands in 2004 with a limited number of islands and sites having been surveyed to date. From these surveys, there are 17 potential disease states that have been documented from the reefs of the Hawaiian archipelgo affecting the four main coral genera (*Porites, Pocillopora, Montipora, Acropora).*

Although the study of coral disease within Hawaii is still in its infancy, a number of patterns are starting to emerge. Aeby (in press) and Aeby and Work (unpub. data) found that the most common disease in both the main and northwestern Hawaiian Islands is *Porites* trematodiasis. There were differences in prevalence and types of disease both within each of the regions (NWHI and MHI) as well as across regions. One major difference between regions was in the frequency of occurrence of growth anomalies in two coral genera (*Porites* and *Montipora*). *Porites* growth anomalies were found at 60% of the sites surveyed in the MHI compared to 5.2% of the sites within the NWHI. Likewise, *Montipora* growth anomalies were found at 25% of the MHI sites compared to 4.5% of the NWHI sites. The level and types of diseases differed between the four dominant coral genera with *Porites* having the highest prevalence of disease and *Pocillopora* having the lowest. Baseline surveys need to be completed within the main Hawaiian Islands and research is needed to understand the different patterns of disease occurrence.

In May 2005, twenty-two permanent sites were established within the NWHI (French Frigate Shoals, Maro Reef, Pearl and Hermes, Midway and Kure) (Aeby and Work, unpub. data). Establishment of permanent sites will allow the assessment of both temporal and spatial changes in diseases through time and determine the ultimate affect of disease and bleaching on the health of the ecosystem.

Investigation of diseases of reef fish and sea turtles

Previous studies on Oahu revealed that the introduced bluestripe snapper (taape) had a high prevalence of infection with protozoa in the spleen and kidney and somewhat lower prevalence of bacterial infections in the same organs (Work et al. 2003). Because protozoa can cause severe mortalities in fish, the question arose as to whether these and other parasites were shared between taape and native fish, such as goatfish, with which they school. Necropsies were conducted on 60 taape and 120 goatfish comprising 5 species including weke`a (yellowstripe), weke`ula (yellowtail), moano (manyband), malu (sidespot), and weke nono (Pfluger's). Prevalence of protozoal infections in taape and yellowstripe goatfish was 50%. Prevalence of similar parasites was >90% in Pfluger's and 30% in yellowtail goatfish. The parasites in all species of fish were similar in morphology and molecular analyses confirmed the protozoal infection (apicomplexa) within taape to belong to the genus *Goussia*. Prevalence of bacterial infection in taape was low (10%) and similar prevalence was seen in manybar, Pfluger's, yellowstripe and yellowtail goatfish. The red nematode, *Spirocamallanus istiblenni* was found in the gastrointestinal tract of 80% of taape, 15% of yellowstripe and 12% of yellowtail goatfish. This study provides compelling evidence that parasites are shared between introduced taape and native goatfish, that prevalence of infection with protozoa in certain species of native fish is far higher than in taape, and that prevalence of infection with nematodes is lower. Future studies need to determine whether these parasites were introduced into Hawaii with taape and what effect they are having on fitness and demographics of native reef fish. Fish from Maui and the NWHI were examined for these diseases in 2005 and results are pending histology.

Okihiro (1988) documented tumors on two species of butterflyfish (*C. miliaris, C. multicinctus*) on Maui and suggested that they could be caused by environmental contaminants. Fish surveys were conducted on Maui in 2005 and it was found that this disease is still in fish populations off Maui but at lower levels than found in the 1980s.

Research on diseases of marine turtles, led by NMFS, has been ongoing for the past 15 years in Hawaii with a focus on fibropapillomatosis (FP), a tumor causing disease found in turtles throughout the Hawaiian archipelago. Salient findings to date include a high prevalence of FP in juvenile turtles, that the disease can be fatal in moderate to severe cases, that turtles are also infected with vascular flukes, that FP is associated with a herpes virus, and that turtles with FP can become immunosuppressed. Efforts are under way to try and isolate the herpes virus associated with the tumors.

Chapter 3: Objectives and Projects

Hawaii's Climate Change and Marine Disease Local Action Strategy

Objective 1	Priority Rank	Funding Status
To support research that provides a scientific basis for managing impacts to reef ecosystems from climate change and disease.	**H, M, or L**	**Unfunded (U) /Partially Funded (PF)**
1.1 Develop baseline knowledge of the types, distribution and prevalence of diseases on the reefs throughout the State of Hawaii. (Separate for corals, key reef fish, turtles, non-coral invertebrates and algae)	**H**	**PF**
1.2 Develop sufficient knowledge about the epizootiology (susceptibility, virulence, mode of transmission, ecology, affect on community structure, etc.) of diseases of concern. This will allow managers to possibly mitigate the cause and effects in the population.	**H**	**U**
1.3 Determine links between disease and bleaching and other stressors such as land-based pollution, fishing effort and marine recreation.	**H**	**U**
1.4 Determine connectivity of reefs at large and small scales, including physical oceanography, genetics and larval dynamics.	**M**	**PF**
1.5 Determine potential effect global climate change may have on acidification, coral growth rates and calcification rates.	**H**	**PF**
1.6 Determine sub lethal impacts from stressors, climate change and disease.	**M**	**PF**
1.7 Identify gaps in existing data from the Marine Gap analysis produced for the main Hawaiian Islands and use that information to determine where further research or monitoring needs to occur.	**L**	**F**
1.8 Gain an understanding as to what factors enhance or inhibit the recovery of corals after a bleaching event.	**M**	**U**
1.9 Use data from the bleaching event that occurred in the MHI in 1996 and the NWHI in 2002 and 2004 to predict reefs at highest risk for bleaching in the MHI.	**M**	**U**
1.10 Develop a comprehensive database on coral reef health. Begin by integrating data from MHI-RAMP, CRAMP, WHAP and DAR on bleaching and disease.	**H**	**PF**
1.11 Develop a research facility capable of supporting advanced disease studies.	**M**	**U**

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Objective 2	Priority Rank	Funding Status
To increase public awareness and engage stakeholders in monitoring and reporting bleaching and disease.	**H, M, or L**	**U / PF**
2.1 Develop Traveling Public Educational Display.	M	U
2.2 Develop a Public Monitoring and Reporting System.	M	U
Objective 3	**Priority Rank**	**Funding Status**
To develop a rapid-response contingency plan for events of bleaching and disease.	**H, M, or L**	**U / PF**
3.1 Develop infrastructure to collect reports of events and initiate response teams.	H	U
3.2 Establish rapid response protocols for events of bleaching or disease.	H	PF
3.3 Establish management protocols for events of bleaching or disease.	M	U
Objective 4	**Priority Rank**	**Funding Status**
To develop proactive and mitigative long-term management strategies to increase resistance and resilience of reef ecosystems to impacts from climate change and marine disease.	**H, M, or L**	**U / PF**
4.1 Develop design recommendations for a network of Marine Protected Areas in the Hawaiian Archipelago that focuses on impacts from bleaching and disease.	M	U
4.2 Develop plan to manage introduction and spread of introduced pathogenic microorganisms of demographic importance.	H	U
4.3 Recommend policy changes in support of management strategies, including the creation of a contingency fund.	L	U
4.4 Support advanced education in disease investigation through partnership with CDHC.	M	U
4.5 Conduct risk assessments of candidate factors influencing disease prevalence.	M	U

Objective 5	Priority Rank	Funding Status
To develop a program to monitor the impacts from climate change and marine disease on the reefs of the Hawaiian archipelago.	**H, M, or L**	**U / PF**
5.1 Develop protocols for post-event monitoring and the capacity to conduct periodic monitoring of reefs that have experienced mass bleaching or disease outbreaks to assess potential community level changes through time.	**H**	**U**

Performance Measures

Hawaii's Climate Change and Marine Disease Local Action Strategy	
Objective 1	**Performance Measure**
To support research that provides a scientific basis for managing impacts to reef ecosystems from climate change and disease.	
1.1 Develop baseline knowledge of the types, distribution and prevalence of diseases on the reefs throughout the State of Hawaii. (Separate for corals, key reef fish, turtles, non-coral invertebrates and algae)	• Baseline data documented in a database that is easily accessible to researchers and managers.
1.2 Develop sufficient knowledge about the epizootiology (susceptibility, virulence, mode of transmission, ecology, effect on community structure, etc.) of diseases of concern. This will allow us to mitigate or eliminate the cause from the population.	• Research findings provided to managers to assist in resource management decisions
1.3 Determine links between disease and bleaching and other stressors such as land-based pollution, fishing effort and marine recreation.	
1.4 Determine connectivity of reefs at large and small scales, including physical oceanography, genetics and larval dynamics.	
1.5 Determine potential effect global climate change may have on acidification, coral growth rates and calcification rates.	
1.6 Determine sub lethal impacts from stressors, climate change and disease.	
1.7 Identify gaps in existing data from the Marine Gap analysis produced for the main Hawaiian Islands and use that information to determine where further research or monitoring needs to occur.	• Research / Monitoring occurs in new areas
1.8 Gain an understanding as to what factors enhance or inhibit the recovery of corals after a bleaching event.	• Research findings that guide management decisions
1.9 Use data from the bleaching event that occurred in the MHI in 1996 and the NWHI in 2002 and 2004 to predict reefs at highest risk for bleaching in the MHI.	• Predictive list developed, monitoring plans reflect priority areas
1.10 Develop a comprehensive database on coral reef health. Begin by integrating data from MHI-RAMP, CRAMP, WHAP and DAR on bleaching and disease.	• Database available and utilized by researchers, managers, and public
1.11 Develop a research facility capable of supporting advanced disease studies.	• Research facility available for use by scientists
Objective 2	**Performance Measure**
To increase public awareness and engage stakeholders in monitoring and reporting bleaching and disease.	
2.1 Develop Traveling Public Educational Display.	• Increased public awareness and involvement, number of volunteers in coral programs, number of calls/reports from public to managers that lead to management actions
2.2 Develop a Public Monitoring and Reporting System.	
Objective 3	**Performance Measure**
To develop a rapid-response contingency plan for events of bleaching and disease.	
3.1 Develop infrastructure to collect reports of events and initiate response teams.	• Information leading to response is timely and events are responded to in a coordinated, efficient manner
3.2 Establish rapid response protocols for events of bleaching or disease.	
3.3 Establish management protocols for events of bleaching or disease.	

Objective 4	Performance Measure
To develop proactive and mitigative long-term management strategies to increase resistance and resilience of reef ecosystems to impacts from climate change and marine disease.	
4.1 Develop design recommendations for a network of Marine Protected Areas in the Hawaiian Archipelago that focuses on impacts from bleaching and disease.	• Recommendations incorporated into future design of MPAs
4.2 Develop plan to manage introduction and spread of introduced pathogenic microorganisms of demographic importance.	• Plan developed
4.3 Recommend policy changes in support of management strategies, including the creation of a contingency fund.	• Policies developed that facilitate rapid response capabilities
4.4 Support advanced education in disease investigation through partnership with CDHC.	• # workshops and courses offered, # students enrolled
4.5 Conduct risk assessments of candidate factors influencing disease prevalence.	• Risk factors identified and risk sources are minimized
Objective 5	**Performance Measure**
To develop a program to monitor the impacts from climate change and marine disease on the reefs of the Hawaiian archipelago.	
5.1 Develop protocols and the capacity to conduct periodic monitoring of reefs that have experienced mass bleaching or disease outbreaks to assess potential community level changes through time.	• Long term monitoring programs provide data that help determine trends

Objective 1: To support research that provides a scientific basis for managing impacts to reef ecosystems from climate change and disease.

1.1 Action: Develop baseline knowledge of the types, distribution and prevalence of diseases on the reefs throughout the State of Hawaii.

Description: The first step in managing diseases is to document what diseases are present in the ecosystem, which organisms are affected and the geographic extent of the different diseases. Systematic disease surveys are needed to develop baseline information on the major organisms on coral reefs including corals, key reef fish, turtles, non-coral invertebrates and algae. In Hawaii, a good baseline of information has been developed for diseases of sea turtles with a limited number of studies on disease having been conducted on corals and fish (see review). Coral and fish studies needed to be completed and systematic surveys of algae and important invertebrates, such as sea urchins, should be conducted.

Project Status: Partially funded
Lead organization: DAR
Cost: $270,000 ($ 90,000 per study/per year)
Project Duration: 3 years
Potential Partner Organizations: NOAA-NMFS, Sea Grant, USGS, DAR, University researchers
Funding Sources: NOAA, HCRI, USGS, DAR, NSF

1.2 Action: Develop sufficient knowledge about the epizootiology (susceptibility, virulence, mode of transmission, ecology, effect on community structure, etc.) of diseases of concern. This will allow managers to possibly mitigate the cause and effects in the population.

Description: Relatively little is known about the impact of disease in marine ecosystems in Hawaii. Introduced pathogens and toxicants have adversely affected native terrestrial wildlife, and most likely a similar phenomenon exists in marine ecosystems. Already, several causes of marine wildlife mortality and morbidity have been identified in Hawaii (coral disease, marine turtle fibropapilloma, fish disease). However, it is unclear whether these diseases are native or were introduced into Hawaii. Because a variety of mortality factors affect wildlife, it is important from a management standpoint to identify those components of morbidity or mortality that are of greatest demographic importance. Such cause of morbidity/mortality are either determined through disease investigations or via necropsy surveys of potentially infected hosts. Once the major mortality/morbidity factors are determined for important species, focused investigations are necessary to determine basic information such as identifying causative agents of mortality/morbidity, determining modes of transmission and circulation within the ecosystem, and understanding environmental parameters and host demographic parameters that encourage the spread or perpetuation of the cause of mortality/morbidity. Such investigations will need participation and collaborations from a variety of experts including marine ecologists, microbiologists, and veterinary diagnosticians. Critical to these investigations will be gaining sufficient understanding to effectively manage or mitigate effects of mortality/morbidity factors on marine ecosystems, thereby contributing to recovery efforts of selected ecosystems.

Project Status: partially funded (some work on turtle and fish disease) Lead organization: USGS, State DOA Cost: $240,000 ($ 80,000 per study/per year) Project Duration: 3 years Potential Partner Organizations: CDHC, NOAA, DAR, academic institutions. Funding Sources: State of Hawaii, NOAA, USFWS, HCRI, USGS, NSF

1.3 Action: Determine links between disease and bleaching and other stressors such as land-based pollution, fishing effort and marine recreation.

Description: Resource managers should consider allowance of human activities within natural resource areas but only to the extent that it is compatible with maintaining those resources. In order to determine the types and extent of activity that should be allowed in a specific area, the effect of these different potential stressors on the resource must be understood. Stress is known to increase an organism's susceptibility to disease. For corals, common stressors include sedimentation, damage due to human activities and the problems inherent with over fishing. Studies are needed to examine the link between stress and coral disease and should encompass two components: the first component would examine the spatial patterns of disease in relation to areas with different levels of human stressors. The second would be to use manipulative experiments to examine the effect of these three stressors (sedimentation, mechanical injury and herbivore density) on the susceptibility of coral to disease.

Project Status: unfunded Lead organization: DNLR Cost: $200,000 ($100,000 per study/per year) Project Duration: 2 years Potential Partner Organizations: Sea Grant, Counties, CZM, DOH Funding Sources: EPA, NOAA, USFWS, Dept. of Health, NIH, NSF

1.4 Action: Determine connectivity of reefs at large and small scales, including physical oceanography, genetics and larval dynamics

Description: In the case of catastrophic events, such as with bleaching or disease, where there may be significant mortality, the key process in replacing lost populations will be through larval recruitment. As such, it is important for managers to have an understanding of the sources of recruitment for different reefs and regions. This requires an understanding of the ocean current patterns, larval biology and historical gene flow among populations. Studies are needed to address each of these components throughout the Hawaiian archipelago.

Currently, studies are underway by Dr. Toonen and Dr. Bowen (HIMB), who are using genetics to quantify patterns and consequences of connectivity in a suite of about 20-30 reef fishes (6 Families) and 20-30 reef invertebrates (6 Phyla) throughout the Hawaiian Archipelago. Dr. Ed DeMartini (NMFS) is conducting a comparative study of geographic connectivity in ecological time (rather than evolutionary time using genetic markers) among metapopulations of shallow-reef fishes, based on elemental chemical "signatures" in the otoliths (earstones) of recruits (recent settlers from the plankton). Recent emphasis has been on comparing additional, representative species between geographic extremes (Hawai'i island in the MHI, the three far northwestern atolls in the NWHI).

NOAA's Coral Reef Ecosystem Division (CRED) has implemented a program that combines various monitoring platforms to measure and record ocean temperatures, salinity, wind and wave energy, tides, currents, available UV-B, and PAR. This provides a time series of high resolution sea surface temperature (SST), sub-surface sea temperature, salinity, PAR, UV-B, air temperature, barometric pressure, and wind direction and speed data to better understand the influences of local environmental conditions on the health of the surrounding coral reef ecosystem.

These monitoring platforms, which include long-term moored observing stations with data telemetry, satellite-tracked drifting buoys, subsurface instrumented moorings and shipboard sensors, are components of NOAA's Coral Reef Ecosystem Integrated Observing System (CREIOS). CREIOS allows for near real-time and long term monitoring, modeling and reporting of biological and physical environmental conditions that influence coral reef ecosystems. The platform allows for the study of the role of ocean circulation on larval transport and recruitment of fish, crustaceans, corals and other marine species (http://www.nmfs.hawaii.edu/cred/oceanography.php).

Project Status: Partially funded, some studies on historic genetic connectivity $150,000 (HIMB)
Lead organization: NOAA
Cost: $600,000 ($ 200,000 per study/per year)
Project Duration: 3 years
Potential Partner Organizations: NOAA, CRED, NMFS, NIMB, DAR, FWS
Funding Sources: NOAA, NSF, USGS, NASA

1.5 Action: Determine the potential effect global climate change may have on acidification, coral growth rates and calcification rates and ultimately how these changes may effect reef-building capacity and thus changes in reef valuation.

Description: Coral reefs develop through the net accumulation of calcium carbonate (CaCO3) produced by corals and other calcifying organisms. Coral reef calcification depends on a number of factors such as sea surface temperature and the saturation state of the carbonate mineral aragonite in surface waters. Kleypas et al. (1999) suggest that carbon dioxide levels will rise in seawater due to uptake from anthropogenic sources which in turn will decrease the pH of seawater. Changes in pH will reduce the aragonite saturation state and significantly decrease the rate of calcification. Conversely, McNeil et al. (2004) argue that any reduction in calcification due to changes in seawater chemistry may be offset by increases in calcification due to increased temperatures. Little experimental work has been conducted to substantiate either of these models. This action requires studies examining the relationship between temperature, changes in pH, and coral growth. Some studies are currently underway and are summarized below.

Reef ecosystem goods and services are related to the abundance and diversity of reef corals and reef fish, which are sensitive to climate change (Hoegh-Guldberg 1999, Hoegh-Guldberg et al. 2000). Potential changes in reef valuation are under study by Paul Jokiel (HIMB), Bob Buddemeir (Kansas Geological Survey), Daphne Fautin (Univ of Kansas), and Pieter van Beukering (Institute of Environmental Studies, Vrije Univ.) who are currently developing a multi-parameter model to predict the socioeconomic impact of changes to Hawaii's reefs from global climate change.

Calcification rates of corals are predicted to decrease by one third to one half by the year 2100. A project entitled 'Global climate change induced shifts in seawater carbonate chemistry: effects on coral reef organisms." (Ilsa Kuffner, US Geological Survey, Florida Integrated Science Center, Andreas Andersson, Oceanography Department, University of Hawaii, Paul Jokiel, Hawaii Institute of Marine Biology, Fred Mackenzie, Oceanography Department, University of Hawaii) is currently underway. The purpose of their study is to provide empirical quantification of the decrease in calcification rates predicted for corals by the year 2100, and to simultaneously examine effects on algal and invertebrate communities. Specific hypotheses being tested include: 1) Corals subjected to year 2100 seawater chemistry will have decreased calcification rates compared to corals in control tanks, 2) Coral planulae (larvae) that recruit naturally to the treatment tanks will experience lower growth rates and lower survival rates than those in control tanks, 3) Macroalgal communities that recruit naturally to the treatment tanks will be different that the resulting communities in the control tanks (e.g., algal biomass, community composition), 4) Community productivity and calcification rates will differ in control and treatment tanks, and 5) Invertebrate communities that recruit naturally to the treatment tanks will be different that the resulting communities in the control tanks (e.g., biomass, community composition).

Project Status: partially funded $30,000 (USGS)
Lead organization: NOAA
Cost: $300,000 ($100,000 per study/per year)
Project Duration: 3 years
Potential Partner Organizations: USGS, University of Kansas, Hawaii researchers
Funding Sources: EPA, NSF, NOAA

1.6 Action: Determine sublethal impacts from stressors, climate change and disease.

Description: The question for reef managers is not whether there is a bleaching or disease event, but how these events will ultimately affect the reef resources. One component of these events is the sublethal impacts that could influence the population dynamics of key reef organisms and as such affect the subsequent recovery of reefs. Sub-lethal impacts might include changes in the reproduction, fertilization success, larval development, recruitment or growth of the organisms. This action requires research to understand the sublethal impacts associated with either bleaching or disease events and the development of possible indicators of sublethal impacts such as stress proteins or other bioindicators. Environmental stressors that could have their own inherent sub-lethal impacts on corals reefs, such as poor water quality or increased sea surface temperature, should also be examined.

The impacts of environmental disturbances are immediately reflected in qualitative and quantitative changes in an organism's gene expression. This expression reflects the initiation of biological activities aimed at ameliorating impacts of the exposure. For example, corals exposed to salinity disturbances will suffer osmotic stress, and gene pathways involved in ameliorating the osmotic disturbances will be highly "expressed" in these corals as compared to their non-impacted counterparts. Currently, Dr. Gates (HIMB) is using this gene based approach to develop sublethal indicators in corals. They are working to identify and isolate genes that display unique behavior with respect to a specific stress (temperature, nutrient exposures or salinity). Her lab is also exploring the link between zooxanthellae genotype and disease susceptibility in coral.

Project Status: PF $120,000 (NOAA)
Lead organization: DAR
Cost: $300,000 ($100,000 per year)
Project Duration: 3 years
Potential Partner Organizations: NOAA, EPA, USGS, LBSP LAS, Hawaii researchers
Funding Sources: NOAA, DAR, EPA, USGS, HCRI

1.7 Action: Identify gaps in existing data from the Marine Gap analysis produced for the main Hawaiian Islands and use that information to determine where further research or monitoring needs to occur.

Description: The foundation of the Marine Gap analysis is in the collection, review and integration of available information relating to natural resources of marine near-shore waters into a natural diversity database and GIS. This gives information on the status and distribution of near-shore flora, fauna and habitats. It also has a decision support system to enable the development, review, and refinement of a comprehensive network of Marine Protected Areas. This database can be used to identify spatial gaps in our existing knowledge of Hawaii's coral reefs. This action requires the Marine Gap analysis to be reviewed in terms of information needed for research regarding coral bleaching or disease.

Project Status: Funded
Lead organization: DAR
Cost: $45,000
Project Duration: 6 months, full time
Potential Partner Organizations: TNC, Hawaii Biodiversity and Mapping Center, FWS, HIMB
Funding Sources: NOAA, FWS

1.8 Action: Gain an understanding as to what factors enhance or inhibit the recovery of corals after a bleaching event.

Description: It is predicted that global climate change will result in an increase in the frequency and duration of bleaching events throughout the world. Although, it was thought that the reefs of Hawaii were essentially immune to bleaching a mass-bleaching event in the main Hawaiian Islands in 1996 (Jokiel and Brown 2004) and then in the NWHI in 2002 (Aeby et al. 2003, Kenyon et al. 2006) and 2004 (Kenyon and Brainard in press) showed this to be untrue. Although we are not in a position to change the trajectory of climate change we can gain an understanding of what factors inhibit or enhance a reefs capacity to recover after a bleaching event and from that information make sound management decisions to help our reefs maintain in the face of changing climatic conditions. Suggested studies include manipulative experiments to look at the effect of different stressors on the recovery ability of bleached corals. The three dominant corals, *Porites compressa, Montipora capitata* and *Pocillopora meandrina* would be ideal candidates for investigation. Stressors such as sedimentation, water quality and herbivore density would be important stressors to examine.

Other factors which could affect a coral's ability to recover from bleaching are being studied by Dr. Grotelli (Ohio State Univ.). During bleaching, when corals lose their symbiotic algae, and thus their supply of photosynthetically fixed carbon is dramatically reduced or lost, they must rely on other sources of energy such as stored lipids and carbohydrates, or heterotrophically acquired carbon to sustain their energetic demands. If some corals are better able to acquire carbon by increasing heterotrophic feeding, they may be more likely to survive bleaching and fully recover. Alternatively, if other corals are able to store larger amounts of excess energy reserves during non-bleaching periods (e.g., as lipids), they may be able to sustain themselves by utilizing these reserves until fully recovered. Corals more efficient at utilizing these stored energy reserves, may be more likely to recover from bleaching. All three of these strategies are hypothesized mechanisms used by corals to promote recovery following bleaching. Using two species of Hawaiian coral, Grotelli will be examining some of the underlying mechanisms of carbon acquisition, allocation (storage), and utilization involved in coral recovery following bleaching.

Project Status: partially funded (where is $ from?)
Lead organization: DAR
Cost: $225,000 (75,000 per project)
Project Duration: 3 years
Potential Partner Organizations: University of Kansas, Hawaii researchers
Funding Sources: NSF, NOAA, FWS, HCRI-RP

1.9 Action: Use data from the bleaching event that occurred in the MHI in 1996 and the NWHI in 2002 and 2004 to predict reefs at highest risk for bleaching in the MHI.

Description: When sea surface temperatures rise above the usual summer maxima, there is a potential for coral bleaching. However, whether or not a particular coral bleaches will depend on a number of factors such as water depth, water motion, UV penetration through the water column, and the inherent resistance of that particular coral species. Mass coral bleaching occurred in Hawaii in 1996 (MHI) and in 2002 and 2004 (NWHI). By examining the patterns of bleaching from these events we will be able to gain information as to which corals species are most resistant or susceptible to bleaching and which physical factors (reef depth, water motion) are important in determining coral bleaching. From this information we will be able to predict which reefs in Hawaii would be most susceptible to bleaching in the event of an increase in sea surface temperature. This information will be critical in initiating a rapid response to future bleaching events.

Project Status: unfunded
Lead organization: DAR
Cost: $35,000
Project Duration: 6 months
Potential Partner Organizations: UH, NOAA, CRED & PMNM, TNC
Funding Sources: NOAA, EPA, HCRI,-RP

1.10 Action: Develop a comprehensive database on coral reef health. Begin by integrating data from NWHI-RAMP, MHI-RAMP, CRAMP, WHAP and DAR on bleaching and disease.

Description: Management is tasked with maintaining the health of our coral reef resources. To aide them in this endeavor this action proposes that a comprehensive GIS database be developed integrating all available information related to coral reef health. A number of independent monitoring programs have been developed which examine different aspects of the Hawaiian coral reef ecosystems. Annual surveys throughout the NWHI have been undertaken since 2000 through the combined efforts of DAR, NOAA's PIFSC CRED and NWHI CRER. In 2003, 73 long-term monitoring sites were identified which will be re-surveyed in alternating years by either CRED or NWHI CRER. The Coral Reef Monitoring Program (CRAMP) has been ongoing since 1999 and monitors changes in benthic and fish communities at 30 sites around the main Hawaiian Islands.

The West Hawai'i Aquarium Project (WHAP) was started in 1998 to evaluate the effectiveness of the marine reserve network in West Hawai'i that was created to ensure the sustainability of the aquarium fishery. Their monitoring program was designed to address a number of issues such as to estimate impacts of aquarium fish collecting in West Hawai`i, to evaluate effectiveness of protected areas (Fish Replenishment Areas) in increasing stocks, to document recruitment patterns of aquarium fishes and to characterize benthic habitat and determine fish-habitat associations. They have 23 sites across west Hawaii and 3 sites in east Hawaii. The main Hawaiian Islands Rapid Assessment and Monitoring Program (MHI-RAMP) was initiated in 2005 to survey sites across the islands in areas not monitored by other programs. They collect data on the fish, algae, non-coral invertebrate and coral communities. Fifty-two sites were surveyed in 2005. Another survey cruise is scheduled for summer 2006, and at biennial intervals thereafter.

The Division of Aquatic Resources (DAR) has just been funded to develop a monitoring program within the main Hawaiian Islands which will examine select fish species, coral, algae and non-coral invertebrate communities and will include a coral disease component. This program is set to begin in 2007. The other monitoring programs also have a limited amount of information on coral bleaching and disease.

There is also some information on disease occurrence in other reef organisms such as turtles and fish. Dr. Rodgers (HIMB) has developed an Index of Biological Integrity which examines various anthropogenic and environmental variables which could help explain the patterns of coral occurrence and health. Integrating information from all data sets will give a better understanding of the spatial patterns of bleaching and disease on the reefs as well as allow us to identify areas where more information is needed. This will be useful in choosing appropriate reefs for baseline disease studies and in identifying reefs at risk for either bleaching and/or disease.

Project Status: partially funded $25,000 (NOAA) Lead organization: DAR Cost: $35,000 Project Duration: 1 year Potential Partner Organizations: NOAA, DAR, EPA, FWS, Hawaii researchers, USGS Funding Sources: NOAA,

1.11 Action: Develop a research facility capable of supporting advanced disease studies.

Description: Detailed studies are necessary to understand the infective nature, pathogenesis and etiology of disease. To prevent the spread of diseases, such studies must be conducted in safe and contained manner. No such research facility capable of supporting disease studies currently exists in the State of Hawaii. This action will first involve the planning and design of such a facility follwed by construction and outfitting of the facility.

Project Status: unfunded Lead organization: University of Hawaii Cost: $1 million Project Duration: 3 years Potential Partner Organizations: NOAA, EPA, USGS, DAR, H-DOA Funding Sources: NSF, NIH, State of Hawaii, NOAA

Objective 2: To increase public awareness and engage stakeholders in monitoring and reporting bleaching and disease.

2.1 Action: Develop Traveling Public Educational Display

Description: The local population is generally not aware of the impacts to coral reefs from climate change and marine disease. A traveling exhibit will be developed to educate the general public about the issues and to promote the public monitoring and reporting system. Exhibit design will be contracted to specialists who can create eye-catching visuals and possibly multi-media elements. The display will be made available to places such as the Hanauma Bay Nature Preserve, Waikiki Aquarium, Maui Ocean Center, etc.

Project Status: Unfunded Lead organization: DAR Cost: $35,000 Project Duration: 6 months Potential Partner Organizations: NOAA, EPA, USGS, DAR, H-DOA, CRON Funding Sources: NOAA, DAR, CZM

2.2 Action: Develop a Public Monitoring and Reporting System

Description: The general public can be of great service to management agencies by gathering and reporting information. In both areas of coral bleaching and marine disease, status information is needed for broad geographic coverage.

The public monitoring and reporting system will feed into a three-tiered monitoring program. Members of the general public who have minimal training perform level one monitoring. They will collect basic information on presence/absence of visual lesions and unusual colorations. This is a screening tool to maximize efficiency. Moderately trained scientists and resource managers will perform level two monitoring when suspected bleaching and disease events are reported by the public. Level three monitoring will be performed by experts to confirm the status of the reef in question, take samples for laboratory analysis, and to make recommendations for management according to the rapid response protocols found in the LAS.

The existing national reporting website (www.reefbase.org) will need to be evaluated to ensure that it is locally applicable. If the national website is used, one of the six protocols will need to be selected for use in Hawaii to maintain consistency. Alternatively, a local web site could be developed that would be specifically for Hawaiian use.

Training materials will need to be developed for volunteers. This may include workshop manuals, PowerPoint presentations, field identification cards, etc. Some field identification cards with common Hawaiian diseases and bleaching indices exist, but more basic cards are needed. For example, the untrained general public may need a field card that distinguishes between bleaching, disease, fish bites, or human trampling.

Training workshops will be offered to interested groups of citizens. These may be conducted in conjunction with the Makai Watch Program's biological monitoring training.

Project Status: Unfunded
Lead organization: DAR
Cost: $60,000
Project Duration: 1 year
Partner Organizations: Sea Grant, Reef Check, Ocean tourism community, Hawaiian Tourism Authority,, TNC, Hawaii Wildlife Fund, CORAL Alliance
Funding Sources: HTA, NOAA, FWS, EPA

Objective 3: To develop a rapid-response contingency plan for events of bleaching and disease

3.1 Action: Develop infrastructure to collect reports of events and initiate response teams.

Description: In order to respond to events in a rapid and efficient manner, management agencies must first be informed of such events. This will require the education and participation of stakeholders that are in a position to potentially make field observations (i.e. ocean tourism community, scientists, management agencies). Management agencies must also have an infrastructure in place to receive and follow-up on reports of potential bleaching or disease events. A response team needs to be created, trained and equipped to respond to events and provide assessments regarding the impact of the event and recommendations for mitigation.

Project Status: Unfunded
Lead organization: DAR
Cost: $70,000
Project Duration: 1 year
Potential Partner Organizations: UH, NOAA, USGS, FWS, Ocean tourism community, Hawaii Tourism Authority
Funding Sources: DAR, NOAA, FWS

3.2 Action: Establish rapid response protocols for events of bleaching or disease.

Description: In the event of mass bleaching or disease-related mortality or morbidity events, protocols are needed to ensure that the appropriate types of data are collected in a manner which minimizes further damage (protocols to minimize contagion during disease outbreaks). Local protocols need to be developed that are complimentary to national protocols (CDHC, GBR protocols in 'Handbook for managers for bleaching management'). Rapid response protocols should include field methods for investigation of the event including standardized techniques for collection of samples for follow-up laboratory analyses. Protocols should also be developed for suggested laboratory investigations that include histology, microbiology and molecular techniques.

Project Status: Partially funded $30,000 NOAA, $5,000 DAR
Lead organization: DAR
Cost: $50,000
Project Duration: 1 year
Potential Partner Organizations: NOAA, UH, USGS, DOH, DOA, EPA, FWS
Funding Sources: DAR, NOAA, FWS

3.3 Action: Establish management protocols for events of bleaching or disease.

Description: In the event of mass bleaching or disease-related mortality or morbidity events, protocols are needed to minimize long-term damage to the ecosystem and enhance recovery. Since degradation of coral reef ecosystems can be caused by multiple stressors, minimization of other human impacts to reefs may increase survivorship and recovery from bleaching and disease. Protocols should be developed that will aid managers in responding to mass events in ways that enhance reef recovery such as decreasing recreational activities, fishing activities, and adjacent land use/development in specifically defined areas for specified time periods after mass events. The local protocols for managing bleaching and disease outbreaks should be complimentary with established national protocols such as CDHC and the GBR protocols in 'Handbook for managers for bleaching management'.

Project Status: Unfunded
Lead organization: DAR
Cost: $35,000
Project Duration: 1 year
Partner Organizations: UH, NOAA, USGS, EPA, DOH, CZM
Funding Sources: DAR, NOAA

Objective 4: To develop proactive and mitigative long-term management strategies to increase resistance and resilience of reef ecosystems to impacts from climate change and marine disease.

4.1 Action: Develop design recommendations for a network of Marine Protected Areas in the Hawaiian Archipelago that focuses on impacts from bleaching and disease.

Description: The potentially severe impacts of repeated mass coral bleaching presents a challenge to resource managers working at small geographic scales. Mass bleaching events can be caused by numerous environmental factors that in combination or individually, can influence the susceptibility of corals to bleaching and related mortality. Factors that influence the resistance and resilience of corals to bleaching must be taken into consideration when designing MPA networks. Connectivity, gene flow, bleaching and disease susceptibility, and socio-economic conditions are all important considerations in the design of an MPA network.

The MPA network design must consider three scales: 1) the local scale of different reef environments and habitats within MPAs; 2) the medium scale of factors that can influence environmental conditions for recovery within an MPA; and 3) the distribution of MPAs at a global scale with respect to global environmental and biodiversity patterns. Taking into consideration these scales and the current structure of protected areas in the

Hawaiian Archipelago, recommendations will be developed to revise the current structure of protected areas with increased focus on bleaching and disease events.

Project Status: Unfunded
Lead organization: DAR
Cost: $50,000
Project Duration: 1 year
Partner Organizations: TNC, UH, NOAA, FWS
Funding Sources: DAR, NOAA

4.2 Action: Develop plan to manage introduction and spread of introduced pathogenic microorganisms of demographic importance.

Description: In Hawaii, novel pathogens hitchhiking on introduced organisms have caused significant problems for native terrestrial fauna and flora. Marine ecosystems in Hawaii have also had intentional and unintentional introductions of marine organisms, yet, little is known about the pathogenic micro-organisms that may have been brought in with them or their potential effects on native species. In conjunction with efforts outlined in section 4.1, research must proceed with an eye to developing management activities that can decrease the likelihood of disease outbreaks due to introduced pathogens and decrease the possibility of introducing new micro-organisms. Such work must proceed in conjunction with the Aquatic Invasive Species Management Plan steering committee, which is tasked with implementing recommendations to decrease the likelihood of introducing detrimental microorganisms into Hawaii's marine ecosystems.

Project Status: Unfunded
Lead organization: DLNR-DAR Hawaii Invasive Species Committee
Cost: $20,000
Project Duration: 1 year, part-time
Potential Partner Organizations: University of Hawaii, US Geological Survey, Academic institutions, State Department of Agriculture
Funding Sources: State of Hawaii, NOAA, Department of Interior (USFWS)

4.3 Action: Recommend policy changes in support of management strategies, including the creation of a contingency fund.

Description: In the event of a severe bleaching event or disease outbreak, managing agencies need to have clear policy guidelines in place which facilitate immediate decision making. In addition to having rapid response protocols for these events, policies need to be developed to allow agencies to implement immediate protection measures, such as fishery or recreation closures in impacted areas. For example, a Memorandum of Agreement (MOA) between the agencies could be developed. The need for immediate management activities may preclude the traditional permitting and public review processes. Legally defensible policy statements need to be developed to allow for resource-based decision making in these situations. Additionally, potential funding sources for response efforts will need to be identified and/or established.

Project Status: Unfunded Lead organization: DLNR Cost: $35,000 Project Duration: 6 months, full time Partner Organizations: EPA, DOH, CZM, USGS, FWS, NOAA, DOA Funding Sources: NOAA, EPA

4.4 Action: Support advanced education in disease investigation through partnership with Coral Disease and Health Consortium (CDHC).

Description: Currently, there is no mechanism to translate advances in medicine, cellular physiology, pathology, toxicology, biotechnology, and resource management to the study of coral disease. As a result there is a 1) lack of standardization, 2) inappropriate nomenclature and inadequate descriptive interpretations of gross lesions, and 3) insufficient access to knowledge of basic histology and cellular physiology, the underpinnings of pathology. These deficiencies result in ambiguous and often misleading communication of findings. Coral scientists must be equipped to gain insight into causation of diseases and become better equipped to handle this expanding threat. There is a need for special topic hands-on training workshops in collaboration with the CDHC to develop capacities in areas of pathology, diagnostics, toxicology and outbreak investigation that can assist researchers and managers in identifying stressors, developing links to causation, understanding the effects of stressors on important reef-building corals, and developing a capacity to conduct ecological risk assessments and incorporate them into coral reef management practices.

Project Status: Unfunded Lead organization: NOAA Cost: $180,000 Project Duration: 3 years Potential Partner Organizations: CDHC, HIMB, DAR, USGS Funding Sources: NOAA, NSF

4.5 Action: Conduct risk assessments of candidate factors influencing disease prevalence.

Description: The occurrence or levels of disease in a population can be influenced by a number of different parameters such as the introduction of novel diseases, changes in the virulences of pathogens, or changes in the susceptibility of host organisms. Current methods used in coral reef monitoring protocols cannot directly and unambiguously resolve natural and anthropogenic stressors, nor establish cause-and-effect relationships or provide a prognostic capacity to enable timely policy decisions and effective environmental protection. To effectively respond to global declines in ecosystem condition of coral reefs, we must provide the types of knowledge and technologies that can fulfill the requirements that resource managers have to 1) demonstrate and determine the extent of resource injury/condition, 2) forensically link causal factors to the injured resource, and 3) provide a cohesive set of methods and tools to routinely and consistently evaluate effectiveness of the management response and thus, enhance resource protection.

To incorporate environmental forensics into current assessment protocols, training is needed in the methodologies, implementation and interpretation of evidence collected during such an investigation to resource stewards. This training would be conducted in two phases. Phase I is the conceptual framework for environmental forensic investigations and Phase II is how to execute an investigation. Once these capacities are built at the local level, resource managers should be equipped to conduct sound investigations as circumstances dictate.

Project Status: Unfunded Lead organization: UH Cost: $150,000 ($50,000 x 3) Project Duration: 3 years Potential Partner Organizations: CDHC, HIMB Funding Sources: NOAA, NSF

Objective 5: To develop a program to monitor the impacts from climate change and marine disease on the reefs of the Hawaiian archipelago.

5.1 Action: Develop protocols and the capacity to conduct periodic monitoring of reefs that have experienced mass bleaching, disease outbreaks or have organisms with diseases of concern to assess potential community level changes through time.

Description: Once a bleaching or disease event has occurred it is important to determine the ultimate ecological outcome of these events. This will require periodic monitoring of affected areas through time. Monitoring protocols and the capacity to support the monitoring efforts must also be developed. Management agencies must have both the financial and manpower support available for monitoring efforts.

Since research on marine disease is in its infancy in Hawaii it is not always clear whether a particular disease will result in sufficient damage to the ecosystem to warrant management intervention. Reefs having organisms with diseases of concern need to be monitored to determine whether or not management actions need to be taken.

Project Status: Unfunded Lead organization: DAR Cost: $10,000 Project Duration: 6 months Potential Partner Organizations: University researchers, dive groups, ReefCheck, REEF Funding Sources: NOAA

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